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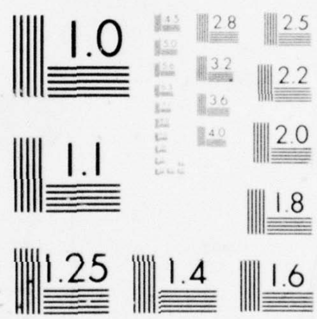

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Snow/Cloud Discrimination

FRANCIS R. VALOVCIN

4 August 1976

METEOROLOGY DIVISION PROJECT 6698
AIR FORCE GEOPHYSICS LABORATORY
HANSCOM AFB, MASSACHUSETTS 01731

AIR FORCE SYSTEMS COMMAND, USAF

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER:

John Howard

Chief Scientist

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The main objective of this investigation was to evaluate the usefulness of the data from the S192 Multispectral Scanner aboard Skylab in snow-cloud discrimination. From the available S192 screening films and digital tape data, the reflectance characteristics of snow, ice, and water clouds in different spectral bands from the visible into the near infrared spectral region can be determined. In the visible part of the spectrum, snow, ice, and water clouds → next page

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appear white. In the near infrared, Band 11 (1.55 to 1.75 μm), water clouds are white, ice clouds are gray and snow is black. The ratio of the radiance values in Band 6 (0.68 to 0.76 μm) to Band 11 (1.55 to 1.75 μm) appears to provide a method for discriminating between snow cover, ice, and water clouds.

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1. INTRODUCTION

The purpose of this report was to evaluate all available data from which a preliminary recommendation could be made regarding a future sensor on the Defense Meteorological Satellite Program (DMSP) satellite to discriminate snow from clouds. The Air Weather Service has a requirement to provide automated snow forecasts. Cloud and/or snow analyses and forecasts are limited due to the ambiguous discrimination between snow and clouds from satellite imagery. A snow-cloud discriminator on board the DMSP satellite could remove these limitations and provide unique real-time data.

2. PREVIOUS RESEARCH

Most of the spectral data on clouds and snow available from the literature have been acquired using different instrumentation and observational techniques. A preliminary report[1] surveyed the literature and pointed out that a water cloud displays two strong absorption bands centered at 1.41 and 1.92 μm. The spectrum of

(Received for publication 3 August 1976)

1. Hunt, G.R., Salisbury, J.W., and Bunting, J.T. (1974) Distinction Between Snow and Cloud in DMSP Satellite Imagery, A Preliminary Report, unpublished, Fourth AFCRL/AWA/SAMSO Satellite Working Group Meeting, AFCRL, Hanscom AFB, Massachusetts, 15 pp.

such a cloud observed from satellite altitudes will be distorted primarily by atmospheric water vapor absorption.

Snow also displays the two strong molecular vibration bands seen in the spectra of liquid water and water vapor but shifted to longer wavelength. These bands lie at a sufficiently long wavelength so that they are distorted relatively little by atmospheric water vapor absorption bands. There are different conditions of snow which yield a slightly different spectra, but all have in common a very low reflectance in the 1.5 to 1.6 μm spectral region as well as near 2.0 μm. Figure 1 shows laboratory spectra of snow and a water cloud. Examination of Figure 1 indicates that in imagery taken through a filter spanning either 1.5 to 1.6 μm or 1.95 to 2.0 μm spectral ranges, snow will show as a dark part of the scene. By contrast, water clouds will remain relatively bright in both these regions, as bright as in the visible part of the spectrum. Laboratory experiments to determine spectral reflectance of snow in red and near infrared were reported by O'Brien and Munis.[2] A typical

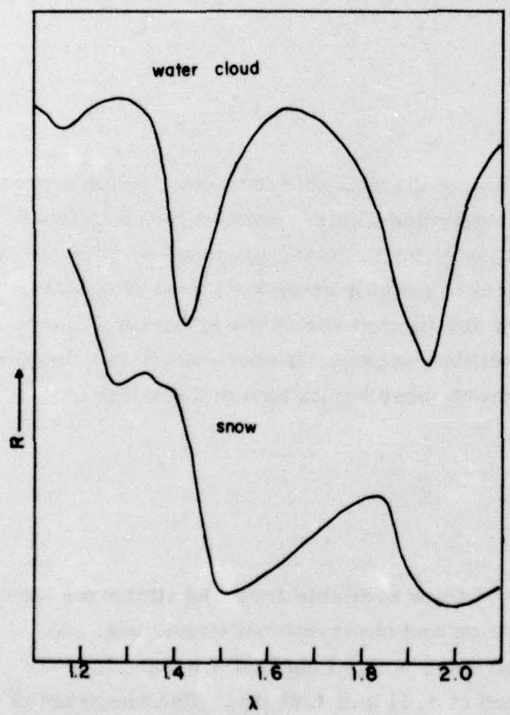


Figure 1. Laboratory Spectra of Snow and a Water Cloud. Reflectance is relative for each curve and the two curves are not drawn to the same scale because the absolute reflectance of the water cloud spectrum was not established

2. O'Brien, H.W. and Munis, R.H. (1975) Red and Near Infrared Spectral Reflectance of Snow, ERP No. 332, U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire, 18 pp.

spectral reflectance for snow relative to a white barium sulfate power is shown in Figure 2. The reflectance of snow is high in the red end of the visible spectrum (0.6 to 0.7 μm). There is a rapid decrease in reflectance from 1.1 to 1.5 μm. The lowest reflectance values occur around 1.5 and 2.0 μm. The literature is not sufficiently informative on attempts to distinguish differences in the reflectances of snow, cirrus, and ice clouds. An artificial ice cloud displays absorption bands in the same spectral regions of 1.5 to 1.6 μm and 1.95 to 2.05 μm as does snow. At 1.5 to 1.6 μm, it appears from the limited data available that ice clouds could be distinguished from water clouds on the basis of their intermediate reflectance. Also, it appears likely that ice clouds will not display a saturated absorption band in this region as compared to snow. Both ice clouds and snow would most likely be saturated in the absorption band in the 1.95 to 2.05 μm spectral region.

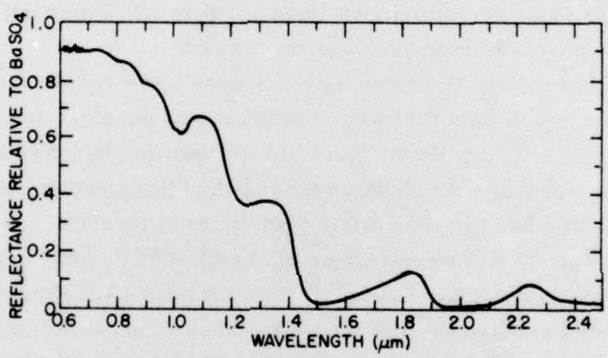


Figure 2. Typical Spectral Reflectance Curve for Snow (from O'Brien and Munis)[2]

3. EXPERIMENTAL DATA

3.1 Skylab Data

The Earth Resources Experiment Package (EREP) on Skylab has provided an opportunity to examine the reflectance characteristics of snow and clouds from the visible to the near-infrared spectral region. Complete descriptions of the Skylab EREP sensors and data products are given in various NASA publications.[3,4] The major effort in this investigation was devoted to the analysis of the following EREP

3. NASA (1973) Skylab Earth Resources Investigations, Office of Manned Space Flight/Office of Applications, 63 pp.

4. NASA (1974) Skylab Earth Resources Data Catalog, Doc. No. JSC-09016, NASA/L. B. Johnson Space Center, Houston, Texas, 359 pp.

Sensors: (a) the EREP S190A, Multispectral Photographic Camera; (b) the EREP S190B, Earth Terrain Camera, and (c) the EREP S192 Multispectral Scanner. Photographic Index and Scene Identification Reports[5,6,7] were published for the various Skylab Missions by NASA and were used primarily to identify snow cover and cloud cover on the various Skylab EREP passes.

The S192 Multispectral Scanner contains 13 bands covering the spectral range from 0.4 to 2.35 μm and 10.2 to 12.5 μm. Twelve of the bands are in the visible through the near-infrared portion of the spectrum. The other band is located in the thermal infrared. The spectral range for each band is shown in Table 1. The conical scan pattern of the S192 covers a swath width of 68.5 km and the instantaneous field of view (IFOV) is 79.3 m^2 of ground coverage. The S192 data output products are 70 mm screening film, digital data on Computer Compatible Tapes (CCT's) and line-straightened final film products. The screening film was not intended to be a high quality film, and, depending on the EREP Pass, only 3 or 4 bands were processed. The Skylab data are voluminous (5 sec of data fill 1 magnetic tape), and relatively little of the voluminous data was processed.

S192 screening films for 17 Skylab EREP passes were received at AFGL and analyzed. The majority of data that were available and received fell into 2 categories; (a) "Right Scene - Wrong Bands" and (b) "Right Bands - Wrong Scene". The "Right Scene" being snow and/or cloud cover and the "Right Bands" being Band 11 (1.55 to 1.75 μm) and a band in the visible part of the spectrum.

Comprehensive study on the evaluation of Skylab EREP data for mapping snow cover has been conducted by Barnes et al.[8] The analysis of S192 imagery and digital tape data indicates a sharp drop in the reflectance of snow in the near infrared. Snow reflectance was essentially non-reflective in Band 11 (1.55 to 1.75 μm) and Band 12 (2.10 to 2.35 μm). An example of the marked drop in the reflectance of snow in the near infrared bands can be seen in Figure 3. S192 imagery over the snow-covered Wasatch Range in Utah shows the high reflectance of snow in Band 2 (0.46 to 0.51 μm) on the left part of Figure 3. Band 11 (1.55 to 1.75 μm) on the right shows the low reflectance (essentially black) in the near infrared spectral range.

5. NASA (1973) Skylab 2 Photographic Index and Scene Identification, Report No. JL 12-601, July 1973, NASA/L.B. Johnson Space Center, Houston, Texas, 127 pp.

6. NASA (1973) Skylab 3 Photographic Index and Scene Identification, Report No. JL 12-602, November 1973, NASA/L.B. Johnson Space Center, Houston, Texas, 251 pp.

7. NASA (1974) Skylab 4 Photographic Index and Scene Identification, Report No. JL 12-603, June 1974, NASA/L.B. Johnson Space Center, Houston, Texas, 335 pp.

8. Barnes, J.C., Smallwood, M.D. and Cogan, J.L. (1975) Study to Develop Improved Spacecraft Snow Survey Methods Using Skylab EREP Data, ERT Document No. 0412F, Final Report, Contract No. NAS 9-13305, Environmental Research & Technology Inc., Concord, Massachusetts, 92 pp.

Table 1. S192 Multispectral Scanner Spectral Bands

Band	Description	Samples/Scan	Spectral Range
1	Violet	1240	0.41 to 0.46 μm
2	Violet-Blue	1240	0.46 to 0.51 μm
3	Blue-Green	2480	0.52 to 0.56 μm
4	Green-Yellow	2480	0.56 to 0.61 μm
5	Orange-Red	2480	0.62 to 0.67 μm
6	Red	2480	0.68 to 0.76 μm
7	Near infrared	2480	0.78 to 0.88 μm
8	Near infrared	1240	0.98 to 1.08 μm
9	Near infrared	1240	1.09 to 1.19 μm
10	Mid infrared	1240	1.20 to 1.30 μm
11	Mid infrared	2480	1.55 to 1.75 μm
12	Mid infrared	2480	2.10 to 2.35 μm
13	Thermal infrared	2480/1240	10.2 to 12.5 μm

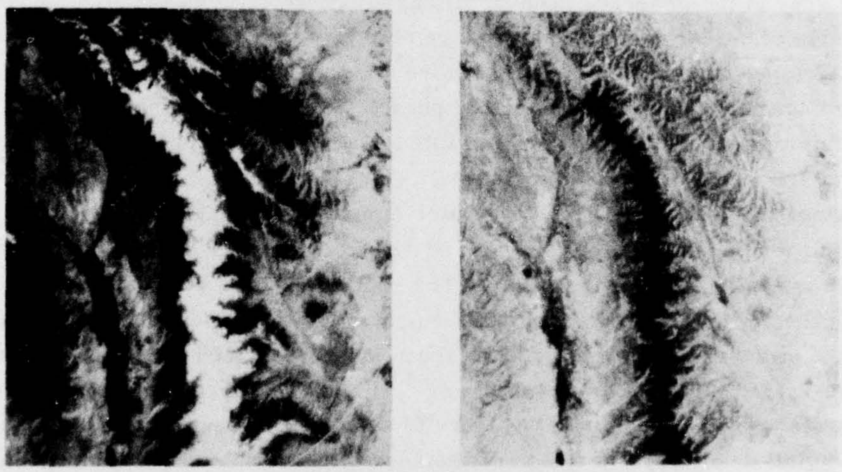
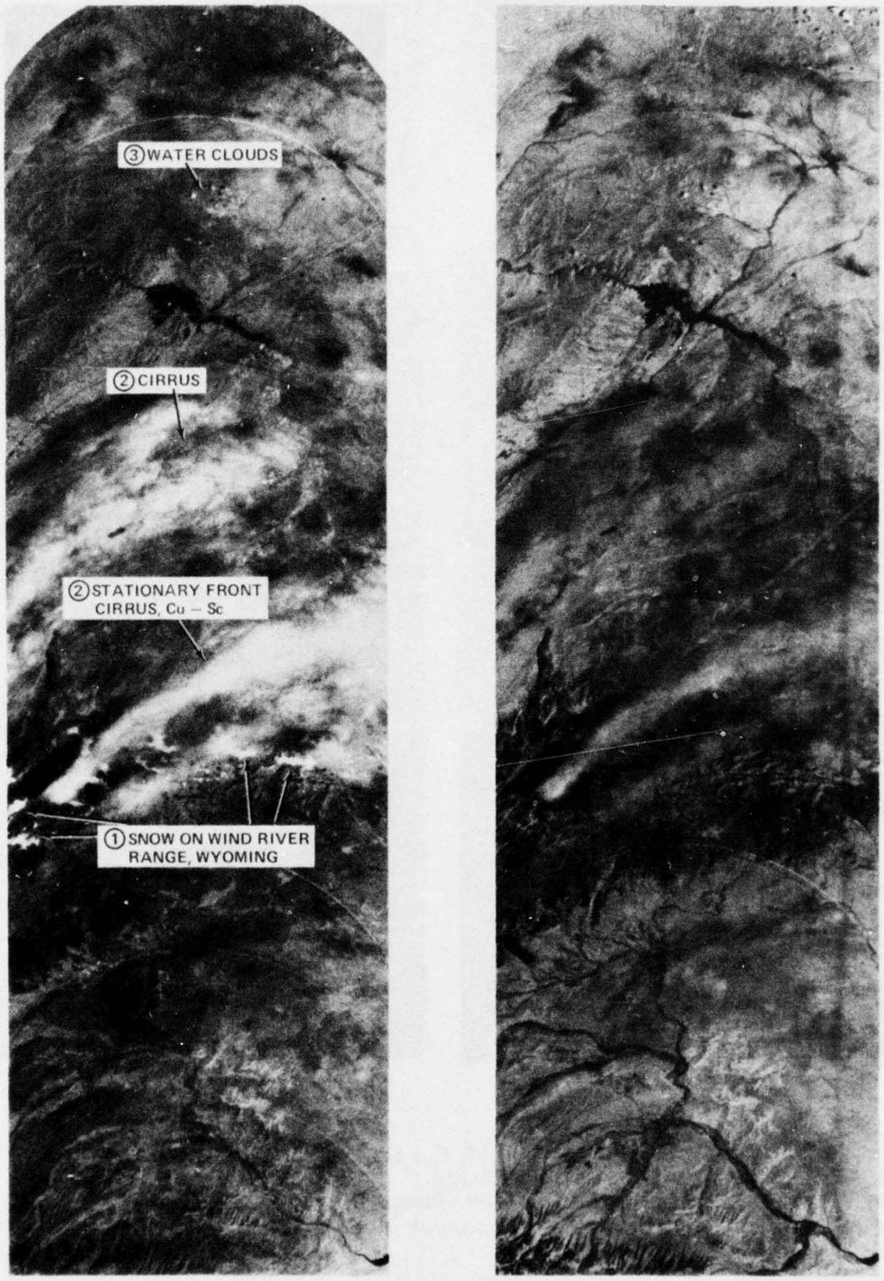


Figure 3. S192 Imagery Over Snow-covered Wasatch Range in Utah. Band 2 (0.46 to 0.51 μm) on the left shows the high reflectance of snow in the violet-blue spectral range. Band 11 (1.55 μm to 1.75 μm) on the right shows the low or absence of reflectance in the near-infrared spectral range. EREP Pass 5, 5 June 1973 (from Barnes et al)[8]

S192 imagery from EREP Pass 37, 13 September 1973 taken over the Wind River Range in Wyoming, is shown in Figure 4. The differences in the reflectance characteristics for snow, ice, and water clouds in Band 7 (0.78 to 0.88 μm) on the left, and Band 11 (1.55 to 1.75 μm) on the right can be seen. Snow in Band 7 0.78 to 0.88 μm) on the left is highly reflective, whereas in Band 11 (1.55 to 1.75 μm) it is non-reflective or black. Just north of the snow covered mountains is a stationary frontal system. The cirrus or ice clouds associated with this system is highly reflective in Band 7 (0.78 to 0.88 μm) on the left, whereas in Band 11 (1.55 to 1.75 μm), the cirrus or ice clouds exhibit a sharp decrease in reflectance. This decrease in Band 11 (1.55 to 1.75 μm) is seen as gray when compared with the "blackness" of snow in this band. In the upper portion of Figure 4, the cumuliform or water clouds remain bright in both bands.

On EREP Pass 20, 12 August 1973, taken over the Gulf of Mexico in the vicinity of Brownsville, Texas, the difference in reflectance of ice and water clouds is shown in Figure 5. Both the large, tall cumulus clouds with ice crystal tops and the small cumulus water clouds are highly reflective in Band 7 (0.78 to 0.88 μm) on the left. The large clouds with ice crystal tops, which cover most of the area, exhibit a sharp decrease in reflectance in Band 11 (1.55 to 1.75 μm) where they appear gray in the imagery. The small cumuli or water clouds located under and to the side of the large cumulus clouds remain highly reflective. This change in the reflectance characteristics between ice and water clouds in the visible and near infrared spectrum can be used in cloud phase, (ice or water) discrimination.

Similar results were observed on EREP Pass 98, 1 February 1974, in an area in the vicinity of Walker Lake in Nevada. The snow exhibits a sharp decrease in reflectance in Band 11, whereas the water clouds remain highly reflective. A typical S192 radiance profile for Bands 6 and 11 for snow cover and for clouds on EREP Pass 98 is shown in Figures 6 and 7. The radiance values were obtained from processing the digital data from the S192 Computer Compatible Tapes. Band 6 (0.68 to 0.76 μm) in the red part of the visible spectrum is saturated at a radiance value equal to 1.46×10^{-2} mw cm^{-2} ster^{-1} μm^{-1}. Band 6 (0.68 to 0.76 μm) is completely saturated for both snow cover (Figure 6) and clouds (Figure 7). This saturation in the digital data indicates a high reflectance in the visible part of the spectrum.



a) b)

Figure 4. S192 Imagery From EREP Pass 37, 13 September 1973. a) Band 7 (0.78 to 0.88 μm) and b) Band 11 (1.55 to 1.75 μm). Area covered is the Wind River Range in Wyoming. (1) snow, (2) cirrus or ice crystal clouds, and (3) water clouds

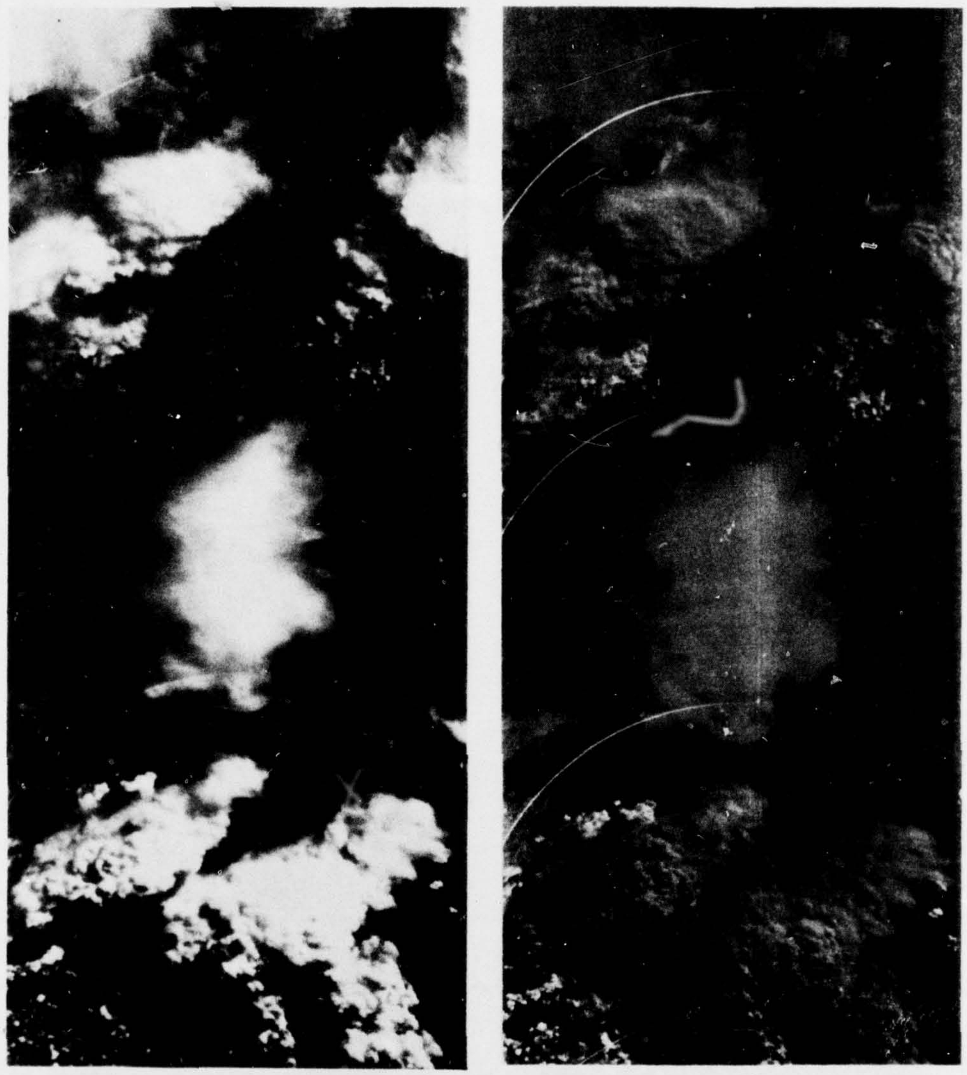

a) b)

Figure 5. S192 Imagery From EREP Pass 20, 12 August 1973. a) Band 7 (0.78 to 0.88 μm) and b) Band 11 (1.55 to 1.75 μm). Area covered is the Gulf of Mexico. Note the reflectance change in the ice clouds whereas the the water clouds do not show much change in reflectance

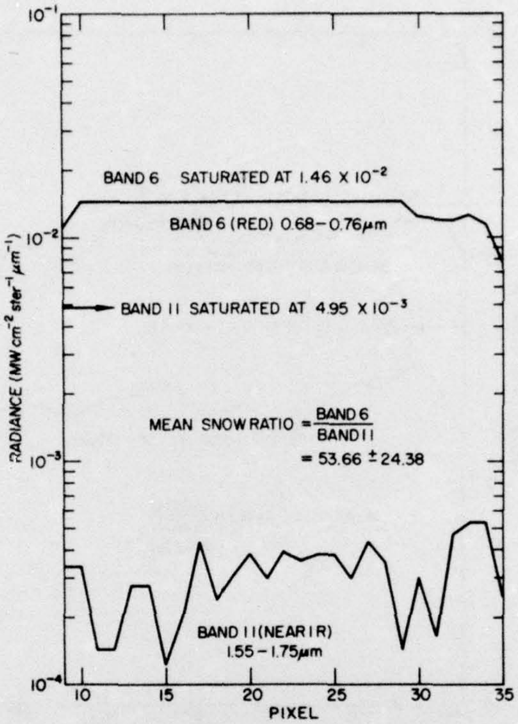


Figure 6. S192 Measured Radiance Profile vs Spectral Band for Snow Cover EREP Pass 98, 1 February 1974, Scanline 640

In the near infrared portion of the spectrum, Band 11 (1.55 to 1.75 μm) is saturated at a radiance value equal to 4.95×10^{-3} mw cm^{-2} ster^{-1} μm^{-1}. The radiance values are much lower in the case of snow in Band 11 (1.55 to 1.75 μm). Generally, the values range from 1.25 to about 5.25×10^{-4}. These radiance values represent digital counts of 8 to 28 compared to 255 counts for saturation in Band 11. If 255 counts represents white, then counts of 8 to 28 would show black on S192 imagery. The mean snow ratio for Band 6/Band 11 is 53.66 ± 24.38. In the case of clouds, the radiance values are much higher. The values range from 1.5 to 3.25×10^{-3} mw cm^{-2} ster^{-1} μm^{-1}. These radiance values represent digital counds of 78 to 168, which would show a relatively high reflectance in Band 11. The mean cloud ratio for Band 6/Band 11 is 5.47 ± 0.79. These are in agreement with Alishouse[9] who used data from the Skylab EREP S191 Infrared Spectrometer Experiment. Using the

9. Alishouse, J.C. (1976) Some Results from a Skylab Cloud Physical Properties Investigation, International Conference on Cloud Physics,: 26-30 July 1976, Boulder, Colorado, AMS, Boston, Massachusetts.

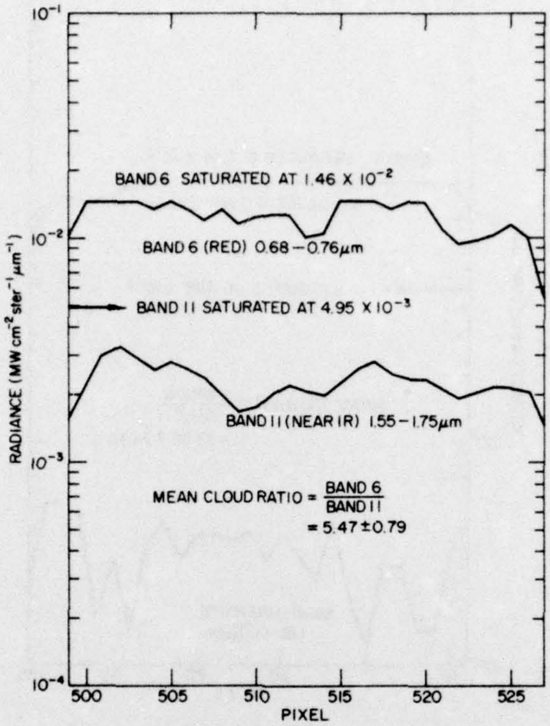


Figure 7. S192 Measured Radiance Profiles vs Spectral Band for Clouds. EREP Pass 98, 1 February 1974, Scan Line 322

ratio of intensity at 0.754 to 1.61 μm for snow, the values range from 25.8 to 61.2; for coastal stratus, the values range from 6.8 to 8.5; and for one case of cirrus, the value was 18.3. Thus, the ratio I (0.754)/I(1.61) appears to provide a way of discriminating among snow cover, ice, and water clouds.

4. CONCLUSIONS

Analysis of pairs of Skylab EREP S192 imagery, one set in the visible spectrum and one set in the near infrared, shows marked differences in the characteristic reflectances of snow, water clouds, and ice clouds in the two bands. While all three scenes have high values of reflectance in the visible spectrum, their reflectances in the near infrared (Skylab Band 11, 1.55 to 1.75 μm) range from high (water clouds), to medium (ice clouds) to very low (snow). This difference, which would be reflected in the ratios of the reflectance in Band 6 (0.68 to 0.76 μm) to that in Band 11, could

be the basis for an automatic procedure which distinguishes among the three different scenes. Based on these data, the ideal band pass for snow/cloud discrimination would start at 1.5 μm and extend to a wavelength no longer than necessary to provide sufficient energy on the detector.

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1. Hunt, G. R., Salisbury, J. W., and Bunting, J. T. (1974) Distinction Between Snow and Cloud in DMSP Satellite Imagery. A Preliminary Report, unpublished, Fourth AFCRL/AWS/SAMSO Satellite Working Group Meeting, AFCRL, Hanscom AFB, Massachusetts, 15 pp.

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